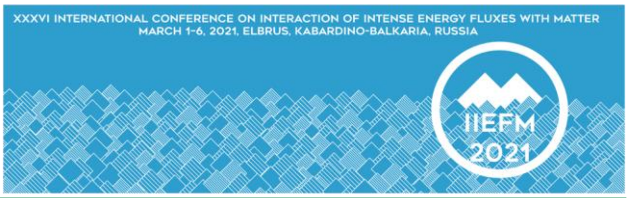

Verification of mathematical model of solid with defects under dynamic loading

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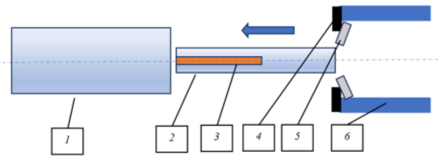
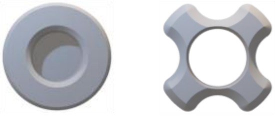
Abstract

The developed mathematical model of a solid with mesoscopic defects was validated on the comparison with experimental data from dynamic tests, including the Hopkinson-Kolsky test and shock-wave loading. The proposed constitutive relations (equations of state) allow the description of the deformation behavior of typical elastoviscoplastic materials (metals and alloys) in a wide range of strain rates, temperatures and stresses. Techniques for estimation of identifying parameters of the model have been developed and based on solving a number of independent problems of minimizing the residuals between the calculated and experimental data. During identification procedure, both literature data and author’s experiments were used. For validation of model an experiment was carried out on high-speed collision of a cylindrical sample with a rod (Taylor-Hopkinson test) combined with registration of the temperature field [1].

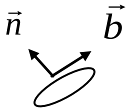


1 - rod, 2 - sample, 3 - IR window, 4 - harrow, 5 - guide, 6 - gas gun



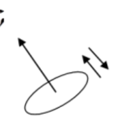
guides made by 3D printing

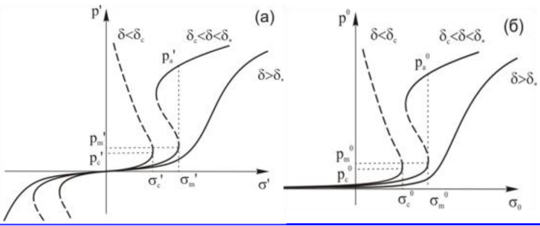
$$E = E_0 - \tilde{H} : \tilde{s} + \alpha \tilde{s} : \tilde{s}$$



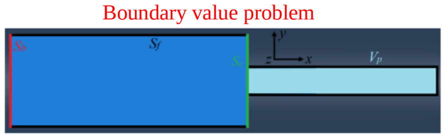
$$W = Z^{-1} Exp\left(-\frac{E}{\theta}\right),$$

$$Z = \int W dv,$$





Boundary value problem



Balance equations

$$\rho \frac{d\mathbf{v}}{dt} = \nabla \cdot \boldsymbol{\sigma}$$

$$\frac{1}{\rho}\frac{d\rho}{dt} = -\nabla \cdot \mathbf{v}$$

$$\rho C \frac{dT}{dt} = \boldsymbol{\sigma} : \dot{\boldsymbol{\varepsilon}}^p - \frac{\partial F}{\partial \mathbf{p}} : \dot{\mathbf{p}}$$

Constitutive equations (EoS)

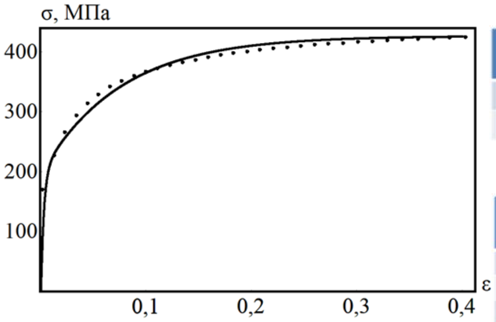
$$\boldsymbol{\sigma}^R = \lambda I_1(\dot{\boldsymbol{\varepsilon}}^e)\mathbf{I} + 2G\dot{\boldsymbol{\varepsilon}}^e$$

$$\dot{\boldsymbol{\varepsilon}}^p = \dot{\varepsilon}_0^{n_\varepsilon} e^{E/kT}\left(\Gamma_\sigma \boldsymbol{\sigma} - \Gamma_{p\sigma}\frac{\partial F}{\partial \mathbf{p}}\right)$$

$$\dot{\mathbf{p}} = \dot{\varepsilon}_0^{n_p} e^{E/kT}\left(\Gamma_{p\sigma} \boldsymbol{\sigma} - \Gamma_p \frac{\partial F}{\partial \mathbf{p}}\right)$$

$$E(T) = \frac{k}{T_c^m} T^{m+1}$$

Model parameters identification problem



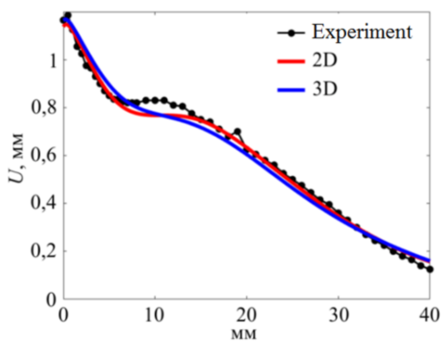
Stress-strain diagram for AlMg6 alloy

Strength VS strain rate

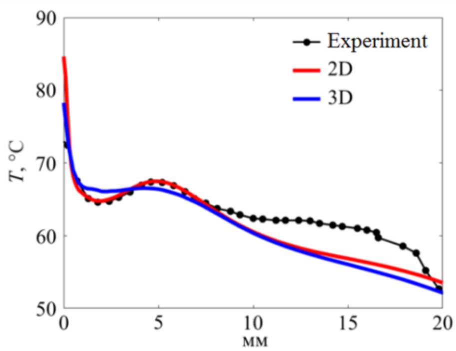
Strain rate, 1/s	Strength (model), MPa	Strength (exp.), MPa
1	164	165
520	176	175

Strength VS temperature

Temperature, °C	Strength (model), MPa	Strength (exp.), MPa
25	164	165
100	153	160
200	117	135
300	72	60

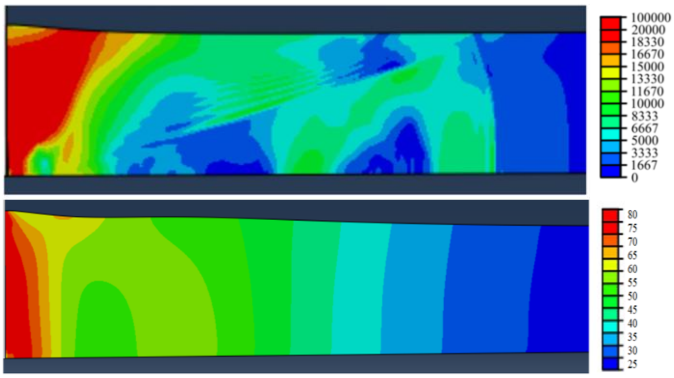


Comparison between numerical simulation results and experimental data for surface displacement



Comparison between numerical simulation results and experimental data for temperature on surface

Results of numerical simulation



Strain rate distribution in sample, 1/s

Temperature distribution in sample, °C

Conclusions

The comparison was carried out by numerical modeling using the finite element method in both three-dimensional and axisymmetric formulations. The results of numerical calculations are in good agreement with the experiments performed: the shape of the rod after collision and the measured temperature (dissipation of mechanical energy during inelastic deformation) coincide. This testifies to the adequacy of the developed mathematical model and indicates the possibility of its application for solving problems in solid mechanics.

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[1] Bayandin Yu.V., Bilalov D.A., Uvarov S.V. Verification of wide-range constitutive relations for elastic-viscoplastic materials using Taylor-Hopkinson test // Computational Continuum Mechanics. – 2020. – V. 13. Is. 4. – P. 449-458.